Study Committee D1

Materials and Emerging Test Techniques

Paper D1-PS1-10177

INTEGRITY EVALUATION OF THERMAL POWER PLANT BASED ON CARBIDE PRECIPITATION SEQUENCE

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Motivation

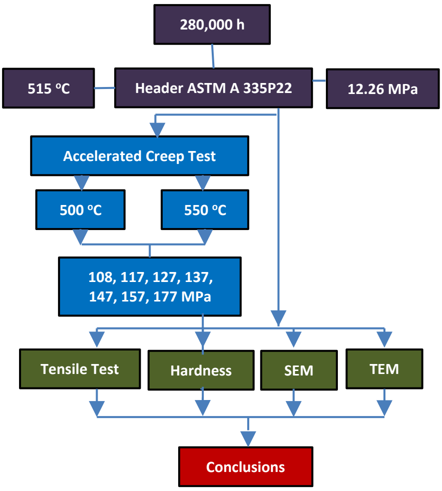
- Thermal and nuclear power plants materials are submitted to high temperature and pressure applications for long time and must be resistant to creep and oxidation.

Cr-Mo ferritic steels are widely used: microstructural and creep degradation

- The literature presents several papers discussing the carbides precipitation at high temperature in thermal power plants ferritic steels but all considering new material accelerated creep tests: short time + high temperature + higher stress than in service.
- Remains the doubt if:
    - the mechanisms that cause the creep material failure under these accelerated conditions are the same as those under the operating conditions;
    - the precipitations and its distribution morphology, strongly associated with diffusion and time dependent phenomenon, occur in a equivalent way.

- **Present paper:** the starting material comes from a thermal power plant header with 280,000 hours of service (32 years).
- This guarantee that a large part of the material aging process occured under real operational conditions.

Method/Approach



- **Optical Microscopy:** microstructural degradation in ferritic-pearlitic 2,25Cr-1Mo steels.
- **Transmission Electron Microscopy (TEM):** degradation with pearlitic or bainitic microstructure by the analysis of the carbide's stoichiometry and morphology.

Test results & Discussion

- Tensile tests result performed on the 280,000 hours aged in service material indicated that there was a loss of material strength when tested at 500 and 550 °C.

Especifica-tion	Temperature (°C)	Yield Stress (MPa)	Ultimate Stress (MPa)	Elonga-tion (%)	Hard-ness (HR_B)
ASTM A335 P22	25	≥ 205	≥ 415	≥ 22	≥ 69
	500	≥ 173	≥ 382	-	-
	525	≥ 167	≥ 334	-	-
Experimental Results	25	234 ± 3	534 ± 3	28.9 ± 0,6	74 ± 4
	500	169 ± 10	313 ± 6	31 ± 2	-
	550	173 ± 19	253 ± 6	35 ± 3	-

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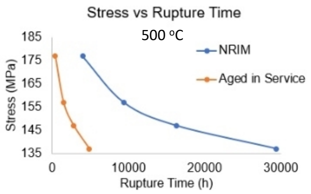
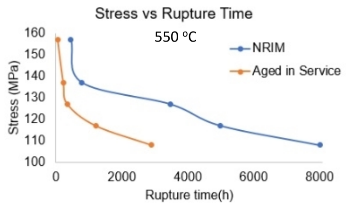
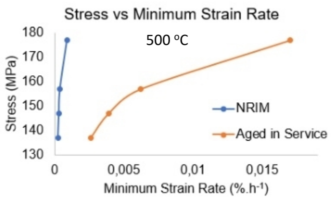
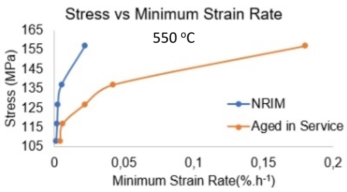
continued

- The results from the creep tests performed on:
  - the 280,000 hours aged in service material;
  - the ASTM A335 P22 steel new material by NRIM.



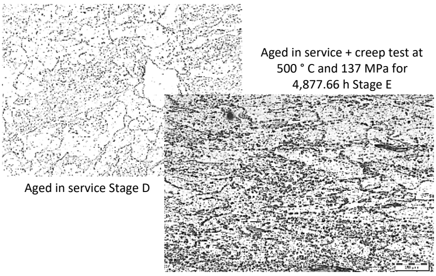






- The aged in-service material reveals significant loss of creep resistance after the long exposure at high temperature and stress.
- This analysis shows the influence of stress on the microstructure of a material subjected to constant loading and high temperature.

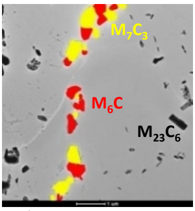
- there is an acceleration in the microstructure degradation of the studied steel, not only with the temperature, but also with **the increase of the stress.**



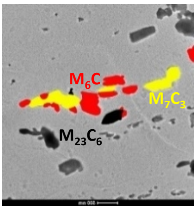
Aged in service + creep test at 500 ° C and 137 MPa for 4,877.66 h Stage E

Aged in service Stage D

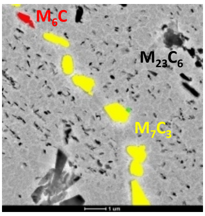
Grain Boundaries Fields



Aged in service + creep test at 500 °C and 137 MPa



Aged in service + creep test at 500 °C and 127 MPa



Aged in service

- The aged in-service material did not present M_3C carbides.
- The M_7C_3 and M_6C carbides forms the largest precipitated volume fraction.
- These observations corroborated the proposed theory: the presence of $M_{23}C_6$ and M_6C is associated with long term ageing and with an advanced stage of microstructural degradation of Cr-Mo steels.

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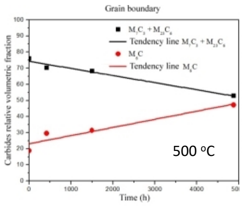
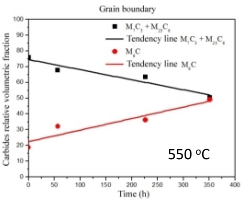
continued

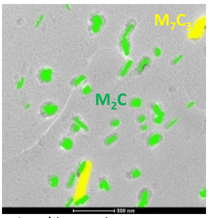
- Dependence between solubilization of M_7C_3 and $M_{23}C_6$ with M_6C precipitation in grain boundaries of samples submitted to creep tests:



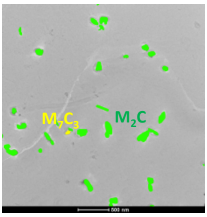


Ferrite Grain Fields:

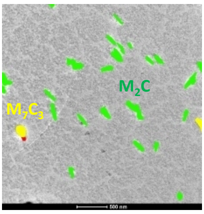
- Predominance of fine and acicular Mo_2C carbides in ferritic grains due to the high initial solubility of Mo in ferrite, in some of the fields reaching values close to 100%.



Aged in service + creep test at 500 °C and 137 MPa



Aged in service + creep test at 500 °C and 127 MPa

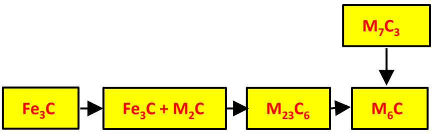


Aged in service

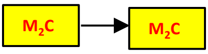
- The intense presence of the carbides M_7C_3, $M_{23}C_6$ and M_6C, the last one considered as a deleterious phase for this steel class, could be an indication that the material is reaching the end of its operating life under creep conditions.

- This shows the importance of characterizing the precipitates in the integrity assessment of a component operating at high temperature
- Precipitation sequence obtained from the aged material in service followed by the samples submitted to the creep tests is a decrease of M_7C_3 and $M_{23}C_6$ with the increase of M_6C.
- As the grain contours are the regions in which the creep phenomenon acts most severely, it is extremely important to monitor precipitation at these.

- Perlite and grain boundaries



- Ferrite:



Conclusion

- The studied steel did not present Fe_3C carbides, showing intense precipitation of M_2C carbides in the ferrite and M_7C_3, $M_{23}C_6$ and M_6C in the previously perlite regions and in the grain bounders.
- The creep test samples indicated that the longer test time the decrease of M_7C_3 and $M_{23}C_6$ is observed while increasing the M_6C volumetric fraction, both in the perlite grains and in the grain boundaries.
- These results can be used as the basis of a methodology to remaining life estimation for this class of steel operating at high temperature under steady state conditions in thermal and nuclear power plants.
- The stress to which the steel is subjected influences in a remarkable way the evolution of its microstructure.
- Periodic inspections are necessary in parallel to monitor the growth of the M_6C volumetric fraction and the degradation state of the microstructure in the components that operate under creep conditions.